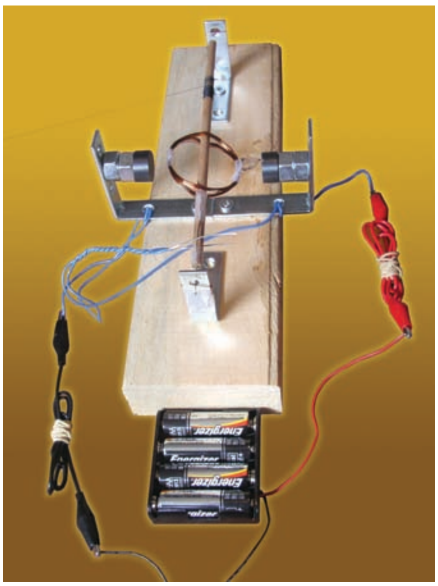
1.4 Electric Circuits

Preparing food for a bunch of people can be a little frantic because so many things are happening at once: the toaster oven is heating up some snacks for dipping, the microwave oven is melting cheese over nachos, the blender is whipping up a frothy fruit drink, and the kettle has just been plugged in to boil water for tea. If you happen to be doing all of this in an older kitchen, you may not be able to operate so many different appliances at the same time. As soon as you turn on one appliance too many, everything shuts down. When this happens, a fuse blows or you hear the loud click of a circuit breaker tripping. In either case, you have gone beyond the limits of what the kitchen circuit can safely handle. This means that you are placing unsafe demands on the circuit. It's time to use fewer appliances at the same time or update the household wiring.



What happens within a circuit to cause the fuse to blow or the circuit breaker to trip? What role do fuses and circuit breakers play in keeping you safe? You will have opportunities to answer these questions as you explore the properties of electric circuits in this lesson.

As the name implies, an electric circuit involves a circle or closed loop for moving charges that form an electric current. What causes charges to move from one point in a circuit to another?

In your previous work with motors, a battery pack was the source of energy for the electric current that flowed through the rotating coil of the armature. The battery pack produced an electric field within and parallel to the wire that connected to it. The electric field exerted a force on free electrons within the wire, causing the electrons to move. As long as contact was made with the battery pack, the electric field was maintained within the wire and charges flowed, creating an electric current.

This lesson will take things a step further as the circuits will include other devices in addition to the wires and a source of voltage. In the next investigation you will use small light bulbs as you identify the characteristics of electric circuits.

Try This Activity

Building Simple Circuits

Purpose

You will build simple circuits that will allow two small light bulbs to glow.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 4 AA cells in a plastic battery pack
- 4 test leads
- 2 mini light bulbs with bases

Procedure

step 1: Use the materials to build a simple circuit that allows both bulbs to emit light energy. Sketch this circuit.

step 2: Without removing batteries from the battery pack, build a new circuit that causes the bulbs to emit a different amount of light than in step 1. Sketch this circuit.

Analysis

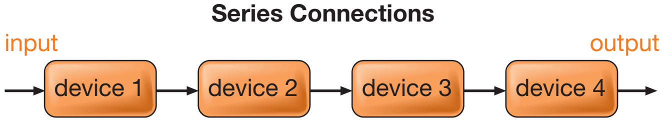
1. List the three essential parts that must be present in all electric circuits.
2. When things are arranged one after the other, it is often called a series. Identify which of your circuits used a series connection between the bulbs by adding the label “series connection” to that diagram.
3. Lines on loose-leaf paper are parallel to one another. Identify which of your circuits used a parallel connection between the bulbs by adding the label “parallel connection” to that diagram.
4. Suggest a reason why one circuit causes the bulbs to emit more light than the other.

Series and Parallel Connections

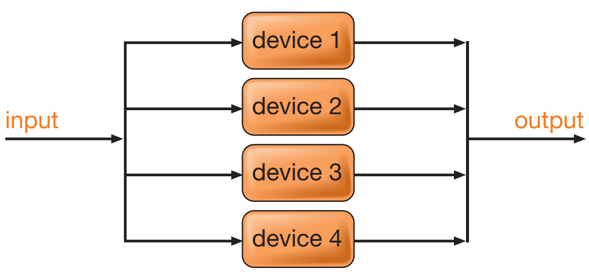
As demonstrated in the “Building Simple Circuits” activity, the best way to learn about electric circuits is to build and test them yourself. As you build circuits in this lesson, you will sometimes be asked to make a **series connection** or a **parallel connection**. Series connections involve the components being arranged one after the other so that the electric current has only one path to follow. Parallel connections provide multiple pathways so that the electric current has to divide and flow through each branch of the circuit.

The first place you will use the ideas of series and parallel connections is with the use of a digital multimeter to measure voltage and electric current in a circuit. Note that when a multimeter is set up to measure voltage, it can be called a **voltmeter** because it is measuring the number of volts. Similarly, when a multimeter is set up to measure electric current, it can be called an **ammeter** because it is measuring the number of amperes.

Series Connections



Parallel Connections



- **series connection:** a single path available for electric current, where the charges flow through one device before passing through to the next
- **parallel connection:** more than one path available for electric current, where the electric current divides, allowing each portion of the current to simultaneously pass through separate devices
- **voltmeter:** an instrument that measures the voltage across two points in a circuit
- **ammeter:** an instrument that measures the electric current flowing through a component in a circuit

Utilizing Technology

Working with Electric Meters

Purpose

You will use computer software to review the use of a digital multimeter to measure electric current and voltage.

Procedure

step 1: Locate the applet "Working with Electric Meters" on the Science 30 Textbook CD.

step 2: Complete all parts of the applet by following the instructions and by answering the questions provided.

Analysis

1. Describe the proper way to connect a voltmeter to a device in a circuit.
2. Describe the proper way to connect an ammeter to a device in a circuit.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Measuring Voltage and Current

A digital multimeter is a useful tool because this one device can measure both voltage and current values in an electric circuit. The convenience of having one machine that can measure a number of different values does have its disadvantages, though. You have to be clear about which quantity you are measuring—current or voltage. Then you have to make sure that the following three things are properly adjusted:

- The dial on the meter is set to measure the desired quantity (current or voltage).
- The test leads of the meter are correctly positioned to measure the desired quantity.
- The circuit has the meter in series to measure current or in parallel to measure voltage.

If you forget one of these details, you may not be able to make accurate measurements and you could blow a fuse in the multimeter.

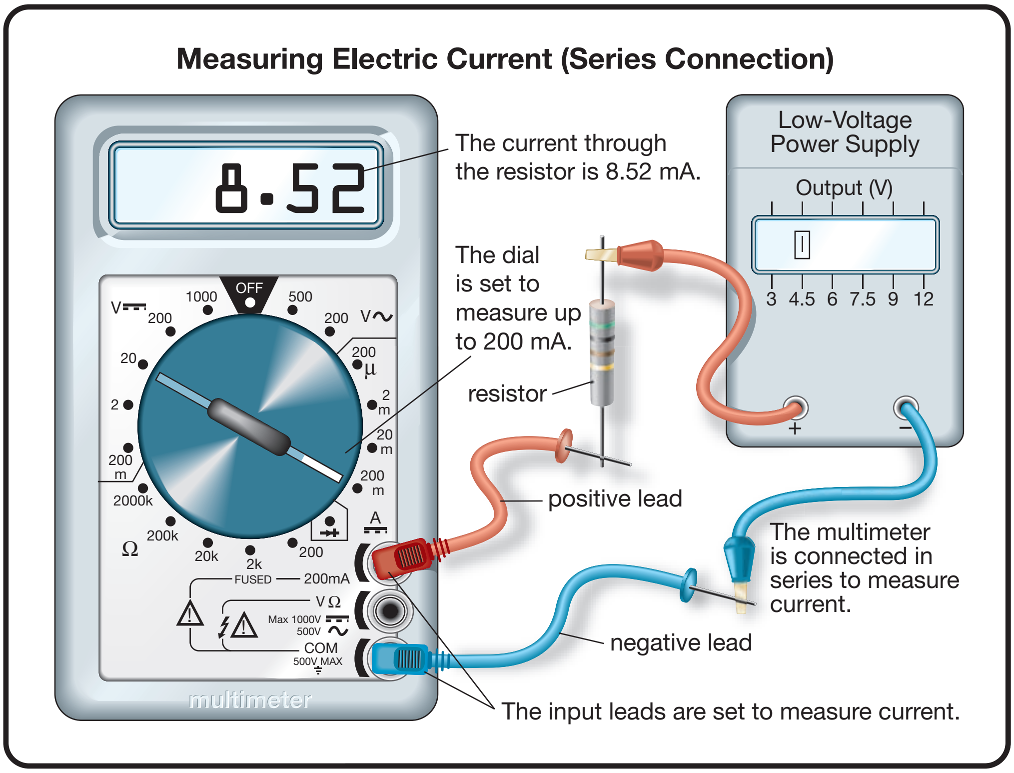


Figure C1.39: Use a series connection to measure electric current with a multimeter.

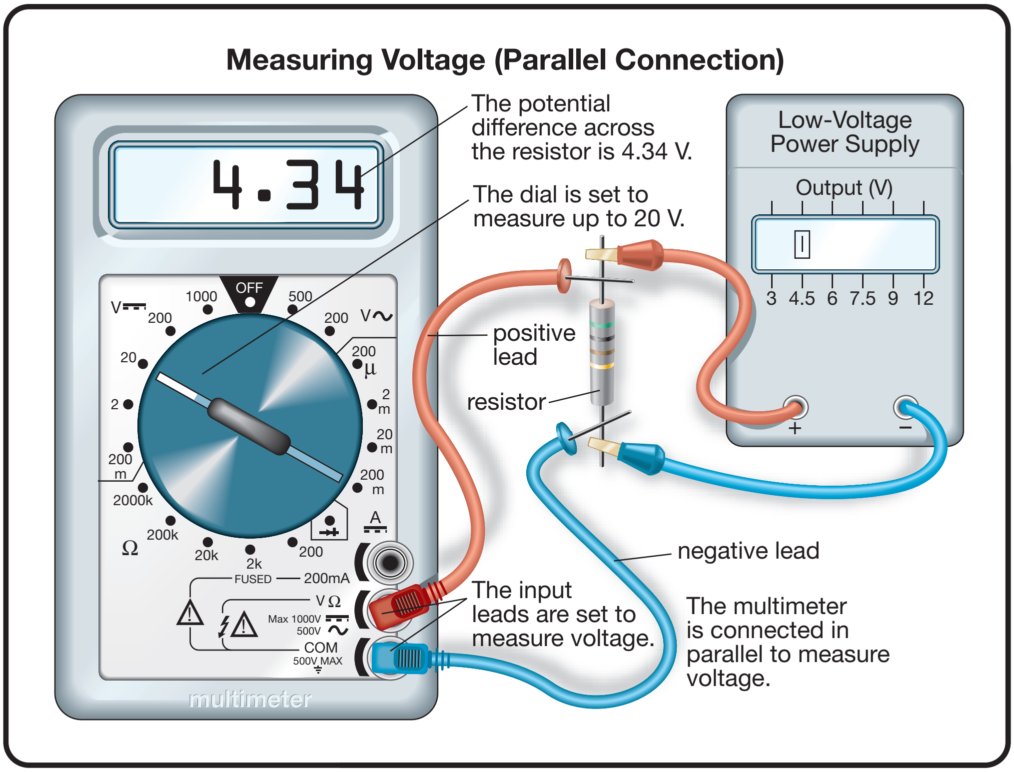


Figure C1.40: Use a parallel connection to measure voltage with a multimeter.

Practice

31. Obtain the handout “Multimeter Troubleshooting” from the Science 30 Textbook CD. For each of the set-ups shown on the handout, describe the changes that must be made to correctly make the desired measurement.

Resistance

In modern electronic devices, you will likely find a number of tiny striped cylinders like those shown in Figure C1.41. These devices can serve a number of purposes, but they are usually used to reduce the current that is sent to some other part of a circuit. Since these devices resist the flow of electric current, each one is called a **resistor**. In some circumstances, the resistor is used to ensure that the current sent to some other device is within safe limits. In the case of motors, resistors connected in series with the motor can be used to regulate the speed of the motor.

Figure C1.41: Resistors

Resistors are rated in terms of the voltage it takes to cause a quantity of current to flow. The ratio of the voltage applied across the ends of a device to the current that flows through the device is called **resistance**. This is one quantity where the name nicely describes what is going on—if it takes a larger voltage to cause a certain amount of current to flow, then there must be a greater resistance to the flow of charges. The equation for resistance makes this even clearer.

resistor: an electronic component that resists the flow of electric current in a circuit

resistance: the ratio of the voltage across a device to the current flowing through it

resistance of a device (Ω)

voltage across the device (V)

$$R = \frac{V}{I}$$

electric current flowing through the device (A)

$$\text{Units: } 1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

Note: The symbol for the ohm is the Greek letter *omega*, Ω.

The unit for resistance is named after George Ohm, a German scientist who did much of the early research into the ability of different types of wire to carry electric current. Ohm discovered that some materials maintain a constant ratio of voltage to current over a considerable range of values. If this is the case, then the equation for resistance becomes a useful tool for predicting the behaviour of the material. In these cases, the resistance equation is usually rearranged and called Ohm's law.

Ohm's Law

$$V = IR$$

Example Problem 1.9

A headlight in an automobile draws a current of 5.0 A from the car's 12.0-V battery.

a. Is the current passing through the headlight AC or DC?

b. Determine the resistance of the headlight while it is operating.

Solution

a. Since the source of the electric current is the car's battery, this is an example of direct current, or DC.

b. $I = 5.0\text{ A}$

$V = 12.0\text{ V}$

$R = ?$

$$V = IR$$

$$R = \frac{V}{I} = \frac{12.0\text{ V}}{5.0\text{ A}} = 2.4\text{ V/A} = 2.4\ \Omega$$

The resistance of the headlight while it is operating is 2.4 Ω.

Materials will offer resistance to the flow of charges whether they travel in one direction, the opposite direction, or back and forth through the material. That's why resistance can be calculated for both components in direct current (DC) and alternating current (AC) circuits.

Example Problem 1.10

A light bulb in a typical lamp is connected to the 120-V wall outlet. When the bulb is operating, it has a resistance of 240 Ω.

a. Is the current passing through the bulb AC or DC?

b. Determine the value of the electric current that is passing through the bulb.

Solution

a. All household circuitry is designed around alternating current. Therefore, the current through the bulb is AC.

b. $V = 120\text{ V}$

$R = 240\ \Omega = 240\text{ V/A}$

$I = ?$

$$V = IR$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{240\text{ V/A}} = 0.500\text{ A}$$

The current passing through the bulb is 0.500 A.

Practice

32. A low-intensity light bulb illuminates the numbers on the outside of a house. The bulb is operated by one of the 120-V household circuits and draws 0.25 A.

a. Is the current passing through the bulb AC or DC?

b. Determine the resistance of the bulb while it is operating.

33. The four cells in a flashlight form a battery with a total voltage of 6.0 V. When the flashlight is switched on, the resistance of the bulb is 8.0 Ω.

a. Is the current passing through the bulb AC or DC?

b. Determine the value of the current passing through the bulb.

DID YOU KNOW?

Why are wet locations, like hot tubs, bathrooms, laundry rooms, and kitchen sinks, the typical places for people to get accidental electric shocks?

The dangerous effects of an electrical shock are the result of a current passing through your body. The magnitude of the current depends on the voltage applied by the energy source and the resistance of your body. If you momentarily contact a 120-V source with dry hands, the resistance of your skin is about 100 000 Ω, so the current passing through you is enough to cause a tingling sensation. However, if your hands and feet are wet, then the resistance of your body drops dramatically. As a result of the presence of salts in sweat, the resistance of your body could be as low as 100 Ω. In this case, the electric current would be painful, possibly producing muscular effects that prevent you from letting go of the wire. If these muscular effects extend to the heart, the heart muscle may remain locked in one massive contraction with fatal consequences.

Measuring Resistance

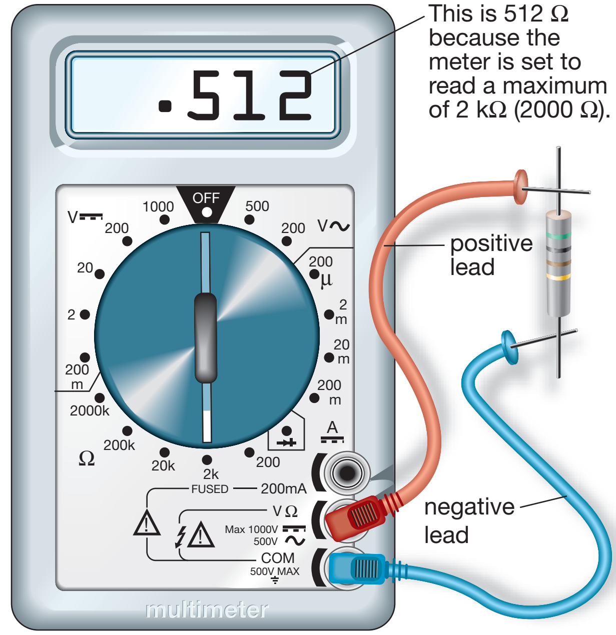


Figure C1.42: Connect the meter across the component to measure resistance.

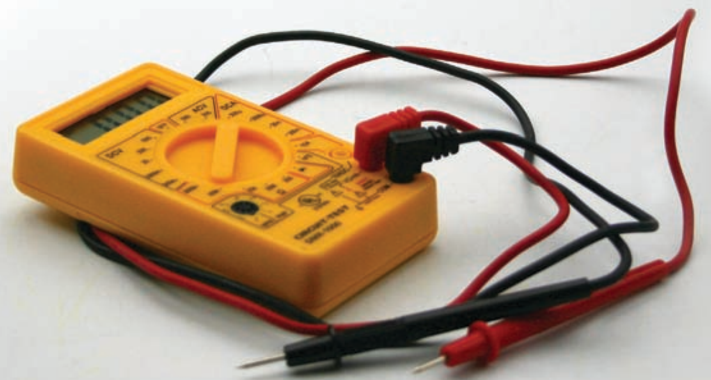
Measuring Resistance

The easiest way to measure resistance is to use a multimeter. Since the dial on the meter will be set for measuring ohms, the meter can be called an **ohmmeter**. As is the case with taking any measurement with an instrument, you have to follow the proper procedure when using the multimeter as an ohmmeter:

- The dial on the meter must be set to measure resistance.
- The test leads of the meter must be correctly positioned to measure resistance.
- The power to the circuit must be switched off and there must be no other components in parallel with the component being measured.
- The meter must be connected across the component being measured.

ohmmeter: an instrument that measures the resistance across two points in a circuit

A typical ohmmeter will give a resistance value that is accurate to within about 1% of the actual value. You can ensure greater accuracy by selecting the lowest range on the ohmmeter that gives a valid reading. However, the best way to determine the value of a resistor is to collect a number of values for voltage and current and then use Ohm's law. In the next investigation you will have an opportunity to compare these two methods for determining the value of a resistor.



Investigation

Comparing Two Ways of Determining Resistance

Purpose

You will design a procedure that will provide two distinct ways of measuring the resistance of a resistor. You then will use your procedure to determine resistance values for three individual resistors.

Science Skills

✓ Initiating and Planning
✓ Performing and Recording
✓ Analyzing and Interpreting

CAUTION!

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electrical outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Replace the fuse inside the meter with only the specified or approved equivalent fuse. Fuse replacement should only be done by the teacher or an adult lab technician.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm—in some cases, hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

Materials

- digital multimeter
- 3 resistors (1000 Ω, 1500 Ω, and 2000 Ω)
- low-voltage power supply or 4 AA cells in a plastic battery pack with 3, 50-mm screws

Process

The end products for this investigation will include the following:

- a detailed diagram that clearly communicates the equipment that is to be used and clearly shows how this equipment is to be connected to the other components
- a data table and clearly communicated calculations for each of the resistors

Analysis

1. If the last coloured band on a resistor is gold, then the actual value of the resistance should be within 5% of the manufacturer's stated values. Determine whether the actual values you determined for the resistors were within this 5% guideline.
2. When evaluating data from an experiment, two key criteria are validity and reliability. Validity refers to the accuracy of the data, or how closely the data matches the actual value. Reliability refers to the consistency within the data. (Will you get the same results if the experiment is repeated?)
   a. Explain which of your two methods for determining resistance is likely to be more reliable.
   b. Explain which of your two methods for determining resistance is likely to be more valid.

Communicating the Details of Electric Circuits

Electric circuits can be found in a vast number of the devices you use every day. The manufacturers that assemble these devices and the people who repair them need a clear way to communicate how circuits are to be assembled and tested. An artist's drawing of the actual components is not practical because it would take up too much space. A more concise way to communicate the details of an electric circuit is to use a **schematic diagram**. Figure C1.43 shows a student's set-up to measure values for current and voltage for a resistor. Figure C1.44 shows the matching schematic diagram.

schematic diagram: a sketch that uses symbols to detail the components of a system such as an electrical circuit

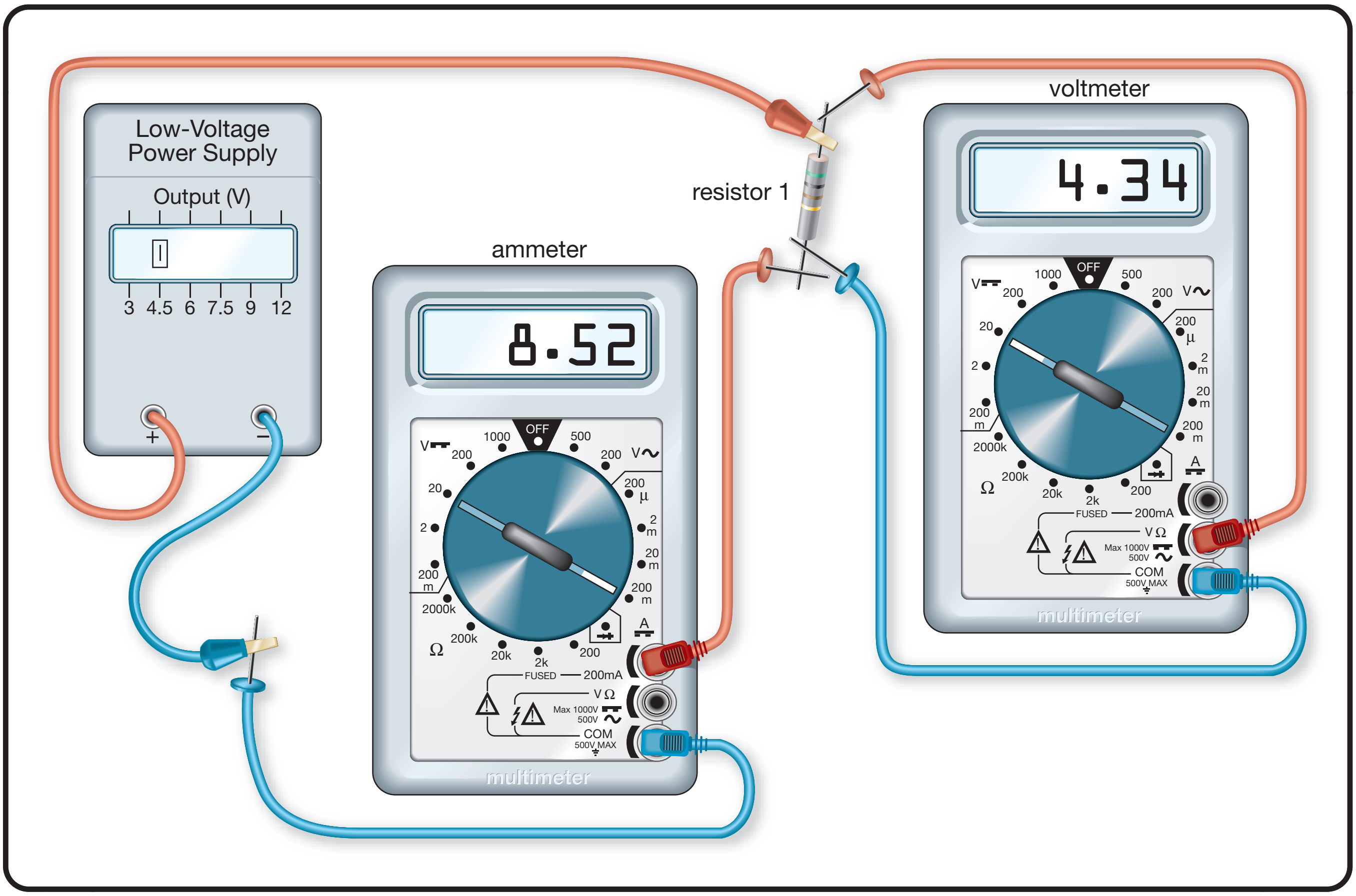


Figure C1.43: This set-up is used by a student to measure values for current and voltage of a resistor.

The schematic diagram uses symbols to represent the key components in the circuit. The schematic keeps things orderly by placing all the wires and components horizontally or vertically. Labels are used to indicate the known values in the circuit or to communicate which component a meter is measuring. The following table summarizes some of the symbols that you could use in your work with electric circuits in this lesson. A complete table of symbols is available on the handout "Symbols for Components in Schematic Diagrams" on the Science 30 Textbook CD.

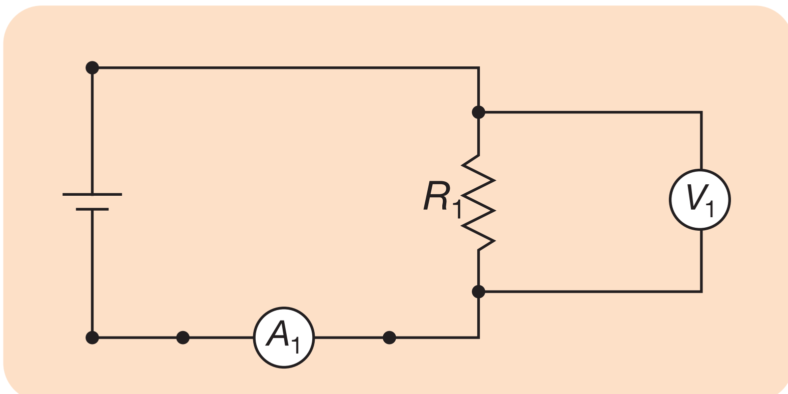
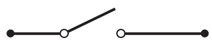
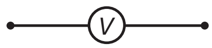
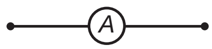


Figure C1.44: This schematic diagram shows the same circuit as Figure C1.43.

SOME SYMBOLS FOR COMPONENTS IN CIRCUIT DIAGRAMS

Component	Circuit Symbol	Function
wire		passes current from one part of a circuit to another
wires joined		connects wires or components
switch		allows current to flow only when the switch is in the closed position
cell or DC power supply	1.5 V 	supplies electrical energy to a circuit in the form of direct current (DC) **Note:** The longer terminal is positive.
battery	6.0 V 	supplies electrical energy to a circuit in the form of direct current (DC)
resistor		resists the flow of electric current
lamp		converts electrical energy into light energy
voltmeter		measures voltage
ammeter		measures electric current
ohmmeter		measures resistance

A great way to practise building circuits with schematic diagrams is to use the software application "Electric Circuits" on the Science 30 Textbook CD. In the next activity you will have an opportunity to explore the properties of different forms of circuits using this software.

Utilizing Technology

Cells in Series and in Parallel

Science Skills
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will use software to determine the effect of adding an additional cell to an existing circuit. One circuit will involve a series connection and one will involve a parallel connection.

Procedure

step 1: Locate "Electric Circuits" on the Science 30 Textbook CD. Open this application and read through the information in the "ShowMe" file to familiarize yourself with the software.

step 2: On the circuit board, construct the three circuits shown in Figure C1.45.

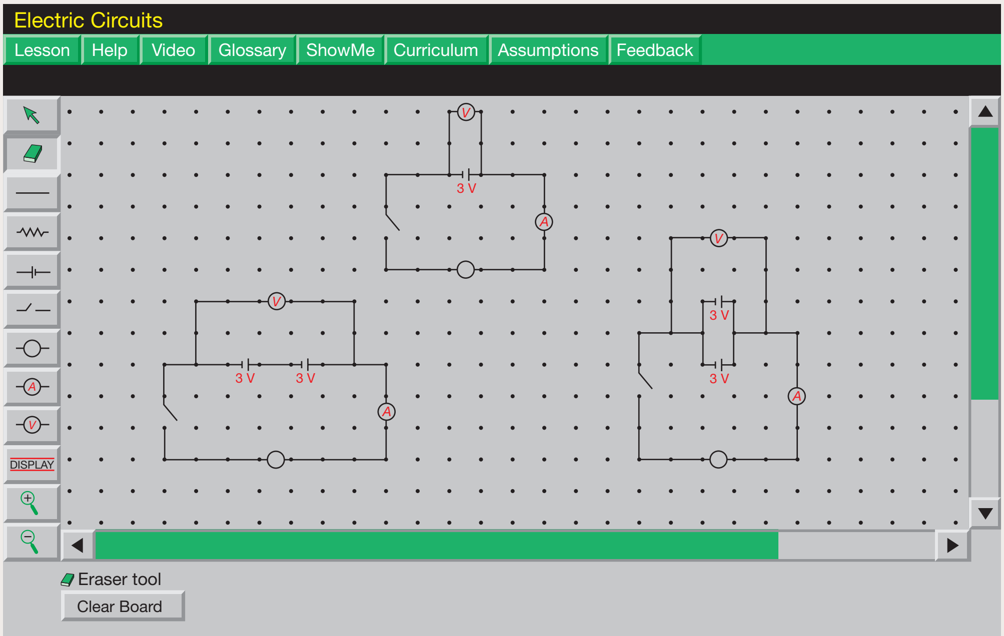


Figure C1.45

Observations

1. The circuit at the top depicts a voltage supply connected in series to a light bulb. Close the switch, record the reading on the voltmeter, and describe the brightness of the bulb.
2. The circuit at the bottom left depicts two voltage supplies connected in series, which are then connected in series to a light bulb. Close the switch, record the reading on the voltmeter, and describe the brightness of the bulb.
3. The circuit at the bottom right depicts two voltage supplies connected in parallel, which are then connected in series to a light bulb. Close the switch, record the reading on the voltmeter, and describe the brightness of the bulb.

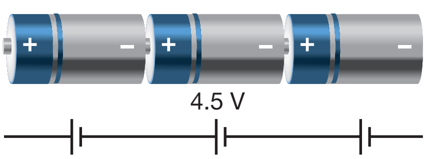
Analysis

4. Two voltage supplies could be connected in series or in parallel. Describe an advantage of each connection.

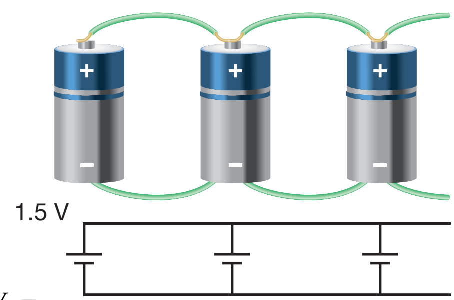
Series and Parallel Connections of Energy Sources

Most graphing calculators use four 1.5-V cells in series to create 6.0 V to run the calculator. What is the advantage of this arrangement? As you saw with your earlier work with the motor, when cells are arranged in series, the energy output to the circuit is increased—the motor turns faster and is able to lift more with higher voltage. The total voltage for a group of cells connected in series can be summarized with the following equation.

$$V_{t_{\text{series}}} = V_1 + V_2 + \ldots$$



If connecting cells in series increases the energy available to the circuit, what is the advantage of connecting cells in parallel? The high-energy output of cells in series means that they can be drained of energy in a shorter period of time. So, it follows that when cells are connected in parallel, they tend to last much longer because the energy output is reduced. The total voltage for a group of identical cells connected in parallel can be summarized with the following equation.



$$V_{t_{\text{parallel}}} = V_1 = V_2 = V_3 = \ldots$$

Example Problem 1.11

Electric service to your home is transmitted through cables that contain three wires. Two of the wires each possess voltages of 120 V, while the third wire is the neutral return wire required to complete the circuit.

a. To operate appliances that demand 120 V, describe the circuit that is required.

b. To operate appliances, like the stove and dryer, that demand 240 V, describe the circuit that is required.

Solution

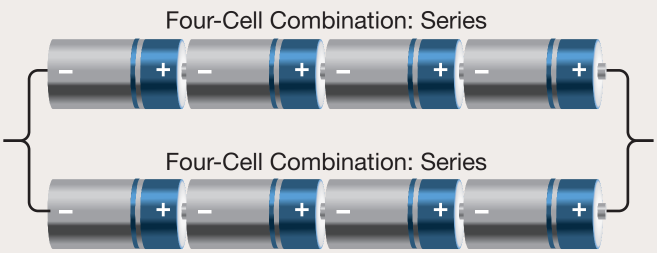
a. When the transmission wires are connected to the circuit, the two wires possessing 120 V each are separated to form parallel paths. The total voltage in each path will be $V_{t_{\text{parallel}}} = V_1 = V_2 = V_3 = 120\ \text{V}$.

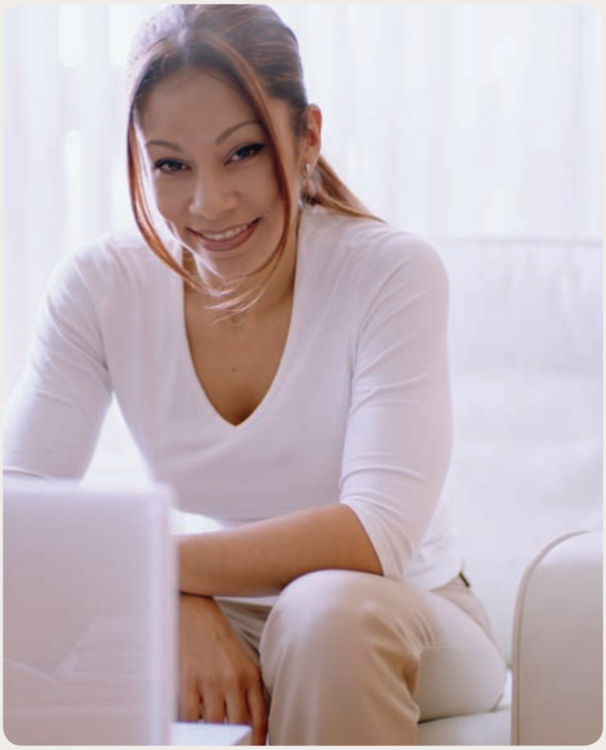
b. When the transmission wires are connected to the circuit, the two wires possessing 120 V each are connected to form a single series path. The total voltage in this path is

$$\begin{aligned} V_{t_{\text{series}}} &= V_1 + V_2 + \ldots \\ &= 120\ \text{V} + 120\ \text{V} \\ &= 240\ \text{V} \end{aligned}$$

Practice

Laptop computers often need battery packs that have both high-energy output and long life. The solution is to combine groups of cells in combination series/parallel arrangements.





Four 3.6-V lithium-ion cells are connected in series to form a four-cell combination. This is then connected in parallel to another four-cell combination to form the laptop's battery pack. This configuration is called 4S2P: four cells in series to form one combination, connected in parallel to a second combination that is identical to the first.

34. If the four cells in each series combination are rated at 3.6 V, determine the total voltage of each set of four cells.

35. Use your answer to question 34 to determine the total voltage of the laptop's battery pack.

Utilizing Technology

Bulbs in Series and in Parallel

Purpose

You will use software to determine the effect of adding an additional light bulb to an existing circuit. One circuit will involve a series connection and one will involve a parallel connection.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Procedure

step 1: Locate the "Electric Circuits" software on the Science 30 Textbook CD. Open this application and read through the information in the "ShowMe" file to familiarize yourself with the software.

step 2: On the circuit board, construct the three circuits shown in figure C1.46.

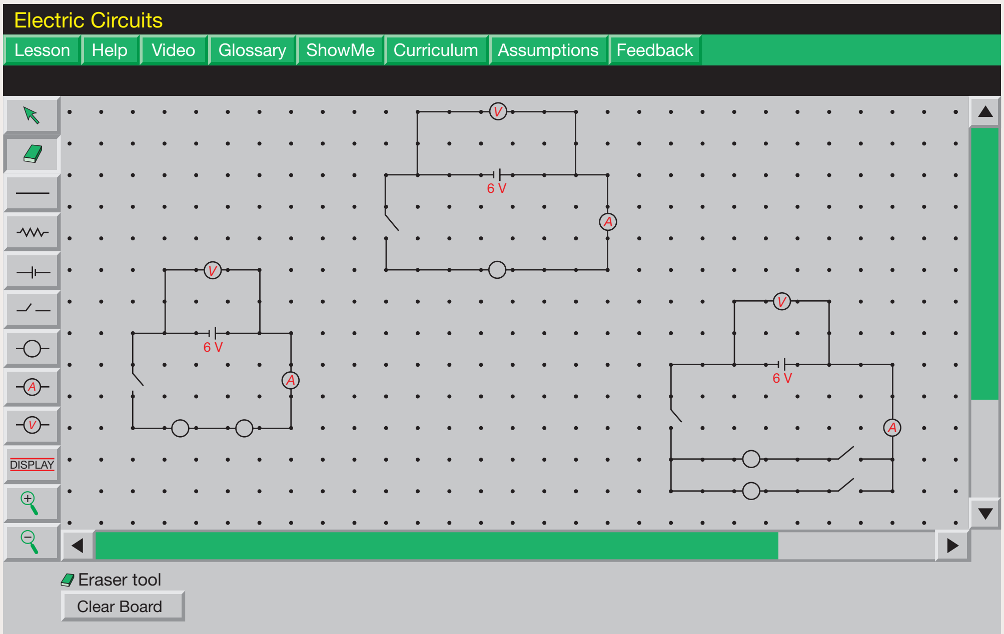


Figure C1.46

Observations

1. The circuit at the top depicts a voltage supply connected in series to a light bulb. Close the switch and record the readings on the voltmeter and the ammeter. Describe the brightness of the bulb.
2. The circuit at the bottom left depicts a voltage supply connected in series to two light bulbs. Close the switch and record the readings on the voltmeter and the ammeter. Describe the brightness of the bulbs. Open and close the switch and note the effect.
3. The circuit at the bottom right depicts a voltage supply connected in series to two light bulbs connected in parallel. Close the switches and record the readings on the voltmeter and the ammeter. Describe the brightness of the bulbs. Open and close each of the switches and note the effects.

Analysis

4. Record the readings on the ammeter and voltmeter in the top circuit.
   - **a.** Use Ohm's law to calculate the resistance of the single bulb in that circuit.
   - **b.** Confirm your answer by using the selection tool (the arrow in the top left corner) to click on the bulb to see the value for its resistance.
5. Record the readings on the ammeter and voltmeter in the bottom left circuit, the one with the two bulbs in series.
   - **a.** Use Ohm's law to calculate the total resistance for the circuit.
   - **b.** Use the selection tool to click on each bulb to see the value for each one's resistance. How do the individual resistance values compare to the total resistance for the whole circuit?

c. Use your answers to questions 5.a. and 5.b. to suggest a rule for determining the total resistance for two identical bulbs in series.

d. Compare the reading on the ammeter in the top circuit with the reading on the ammeter in the circuit with the two bulbs in series. Suggest a reason for the differences.

6. Record the readings on the ammeter and voltmeter in the bottom right circuit, the one with the two resistors in parallel.

a. Use Ohm's law to calculate the total resistance for the circuit.

b. Use the selection tool to click on each bulb to see the value for each one's resistance. How do the individual resistance values compare to the total resistance for the whole circuit?

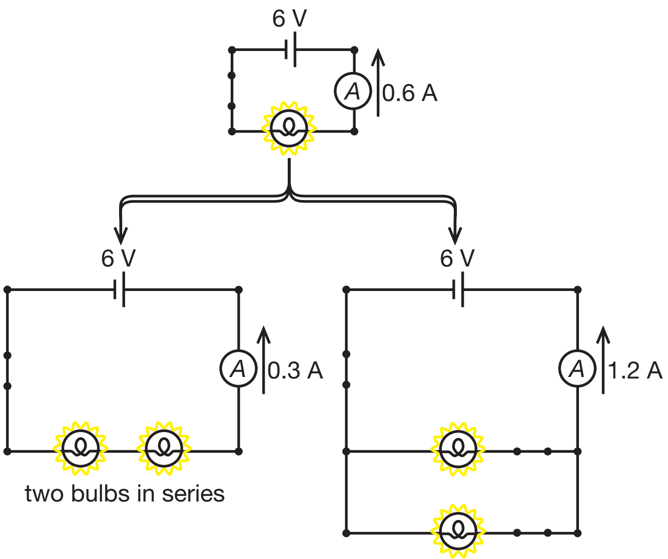
c. Use your answers to questions 6.a. and 6.b. to suggest a rule for determining the total resistance for two identical bulbs in parallel.

d. Compare the current readings of the ammeters in the top circuit with the circuit with the two bulbs in parallel. Suggest a reason for the differences.

7. Describe an advantage and a disadvantage of connecting two light bulbs in series and in parallel.

Equations for Calculating Total Resistance

What happens when an identical light bulb is added to a circuit operating with a single bulb? The results vary depending upon how the additional bulb is connected to the existing bulb.



In the case of the series circuit, there is only one path for the moving charges to follow. If you open the switch in this circuit, or if one of the bulbs fails, the whole thing shuts down. Since the moving charges have to overcome the resistance of the first bulb and then the resistance of the second bulb, the total resistance is equal to the sum of the individual resistances.

For resistors connected in series,

$$R_{total} = R_1 + R_2 + R_3 + \dots$$

Adding the additional bulb in the parallel circuit provides an extra path for charges to follow. One outcome of this extra path is that you can open the switch to one of the bulbs without shutting off the other one. This is why parallel circuitry is so popular with household wiring—you can turn individual devices off and on independently.

Note that the additional light bulb will have the same voltage across it as the original bulb. This stems from the fact that the endpoints of the additional pathway connect to the endpoints of the original pathway. Since practically no energy is lost through the connecting wires, both bulbs have the same difference in energy across their terminals, and, therefore, have the same value of voltage across those terminals.

Perhaps the most important implication of the additional path provided by the extra bulb is the effect on electric current. Since the charges have twice as many paths to follow, twice the current is able to flow. In other words, since the current has doubled, the overall resistance must be only half as much. If a second bulb that is not identical to the first bulb is added in parallel to the circuit, the new total resistance is still lower, but it will not be exactly half as much. The following equation is helpful for determining the total resistance in these circumstances.

For resistors connected in parallel,

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

Example Problem 1.12

Strings of small, colourful lights are often used for holiday decorating and other occasions. An inexpensive string of these lights consists of 8 bulbs connected in series. The resistance of each bulb in the set is 64.0 Ω.

a. Draw a schematic diagram of this circuit.

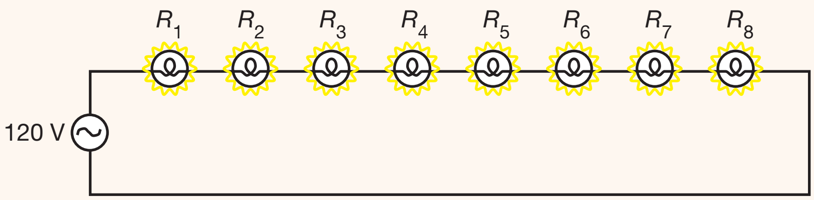
b. If the set of lights is plugged into a 120-V outlet, determine the current that will flow through the set.

c. Use your answer to part a. to determine the current that will flow through the third bulb in the string of lights.

d. If the third bulb in the set fails, determine the effect on the other lights in the string.

Solution

a.



b. step 1: Determine the total resistance.

$$R_1 = R_2 = R_3 = \ldots = R_7 = R_8 = 64.0\,\Omega$$
$$R_{\text{total}} = ?$$

$$\begin{aligned} R_{\text{total}} &= R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 \\ &= 8(64.0\,\Omega) \\ &= 512\,\Omega \end{aligned}$$

The total resistance of all eight bulbs is 512 Ω.

step 2: Determine the current.

$$R = R_{\text{total}} = 512\ \Omega$$
$$V = 120\ V$$
$$I = ?$$

$$\begin{aligned} V &= IR \\ I &= \frac{V}{R} \\ &= \frac{120\ \text{V}}{512\ \Omega} \quad \leftarrow \ \Omega = \text{V/A} \\ &= 0.234\ \text{A} \end{aligned}$$

The current flowing through the entire set is 0.234 A.

c. In a series connection, there is only one path for the electric current. Therefore, the entire electric current flows through each component. This means that the third bulb, as well as every other bulb in the string, will have a current of 0.234 A flowing through it.

d. Since there is only one path for the electric current in a series connection, if one bulb fails, the entire current stops. Therefore, when the third bulb fails, all the other lights go out too.

Example Problem 1.13

A group of students is setting up for a high school dance. They work to set up some spotlights and other types of specialty lighting to help set the mood. Five spotlights are plugged into a heavy-duty power strip, each light in its own outlet. Each of the spotlights has a resistance of 96 Ω.

a. Explain why a power strip must allow parallel connections to each of the devices that plug into it.

b. Draw a schematic diagram of this circuit.

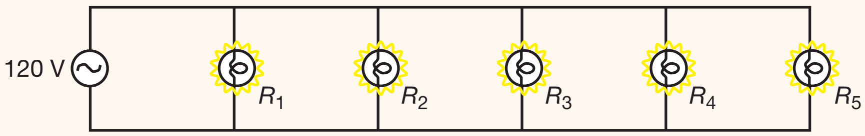
c. If the fourth spotlight has 120 V available to it, determine the voltage available to each of the other spotlights.

d. Determine the total amount of current that the power strip requires to power all five spotlights.

Solution

a. The power strip must allow parallel connections so that each of the devices that plugs into it can be turned off independently. If the power strip operated in series, all the devices would turn off as soon as one device is turned off.

b.



c. Having the same voltage value is an important characteristic of devices connected in parallel. As shown in the schematic diagram, all the spotlights have the same voltage across their wires. Therefore, the potential difference available to each of the other spotlights is 120 V.

d. step 1: Determine the total resistance.

$R_1 = R_2 = R_3 = R_4 = R_5 = 96.0\ \Omega$

$R_{\text{total}} = ?$

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_{\text{total}}} = \left(\frac{1}{96\ \Omega}\right) + \left(\frac{1}{96\ \Omega}\right) + \left(\frac{1}{96\ \Omega}\right) + \left(\frac{1}{96\ \Omega}\right) + \left(\frac{1}{96\ \Omega}\right)$$

$$\frac{1}{R_{\text{total}}} = 5\left(\frac{1}{96.0\ \Omega}\right)$$

$$\frac{1}{R_{\text{total}}} = \frac{5}{96.0\ \Omega}$$

$$R_{\text{total}} = 19.2\ \Omega$$

The total resistance of the five spotlights is 19.2 Ω.

Notes:
- Keep all the intermediate values in your calculator to avoid rounding errors.
- Don't forget to take the reciprocal at the end of the calculation.
- When you do take the reciprocal, use the x^{-1} key.

continued

step 2: Calculate the current.

$R = R_{total} = 19.2\ \Omega$

$V = 120\ V$

$I = ?$

$$V = IR$$

$$I = \frac{V}{R}$$

$$= \frac{120\ V}{19.2\ \Omega} \leftarrow \Omega = V/A$$

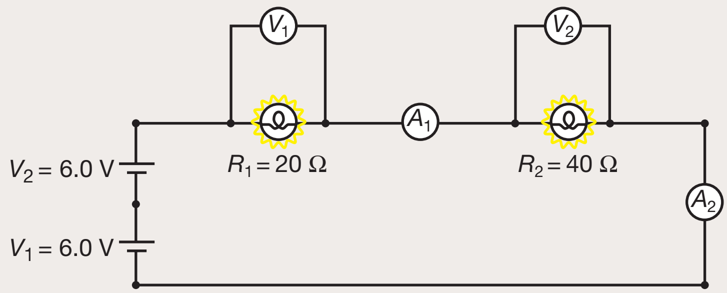
$$= 6.25\ A$$

The current required by all five spotlights is 6.25 A.

These Example Problems illustrate how important it is to first categorize the circuit as being either a series connection or a parallel connection. Once this is done, you can begin to solve the problem. A typical first step is to calculate the total resistance of a number of components. Remember these ideas as you complete the Practice problems.

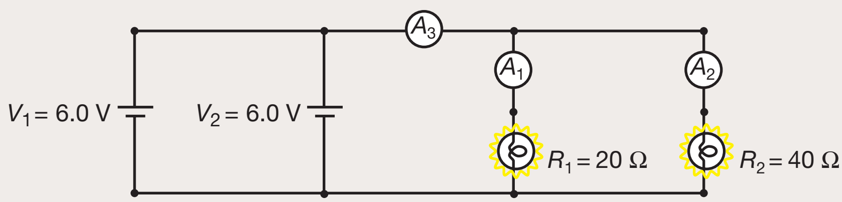
Practice

36. Use the following schematic diagram to answer questions 36.a. to e.



a. Determine the total voltage available to this circuit.
b. Calculate the total resistance of the two bulbs.
c. Calculate the current flowing through each of the bulbs.
d. Calculate the readings of voltmeters 1 and 2.
e. Explain what happens if one of the bulbs burns out.

37. Use the following schematic diagram to answer questions 37.a. to e.



a. Determine the total voltage available to this circuit.
b. Calculate the total resistance of the two bulbs.
c. Calculate the total current flowing through the whole circuit.
d. Determine the readings of ammeters 1, 2, and 3.
e. Explain why the sum of the readings of ammeters 1 and 2 equal the reading of ammeter 3.
f. Explain what happens if one of the bulbs burn out.

Try This Activity

Maximum and Minimum Resistance

Science Skills
- ✓ Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Purpose

You will determine which arrangement of three resistors will produce the maximum and minimum values of total resistance.

Materials

- 3 resistors (1000 Ω, 1500 Ω, and 2000 Ω)
- digital multimeter (used as an ohmmeter)
- test leads

Procedure, Observations, and Analysis

1. Use the multimeter to determine the actual value of each of the resistors.
2. Determine which arrangement of resistors will produce the maximum total resistance. Calculate this maximum value based upon your values from question 1.
3. Use the multimeter to verify your maximum value from the calculations in question 2. Are the values close?
4. Repeat questions 2 and 3 for the arrangement that will produce the minimum resistance.

Circuits with Both Series and Parallel Components

In reality, practical electric circuits use combinations of series and parallel connections. Even the simple kitchen circuit in Figure C1.47 combines both types of connections. The blender and the toaster oven are connected in parallel with the kettle. This ensures that shutting off one device will not shut off either of the others.

Series connections can be found with the switches that control each device. In this case, the ability of a switch to completely stop the flow of current is desirable.

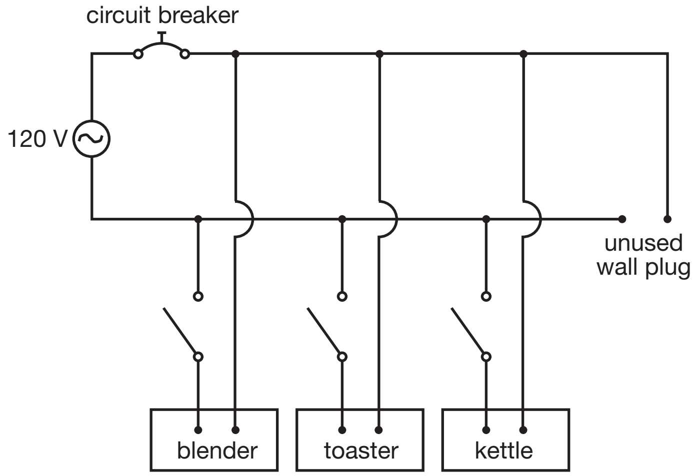


Figure C1.47

This same reasoning explains the series connection of the circuit breaker to all of the other devices on the circuit. This series connection ensures that the total current for the whole circuit must flow through the breaker, allowing the breaker to monitor the current. In most household circuits, the maximum safe current is 15 A. If current values exceed safe values, there is a possibility that the household wiring inside a wall might overheat and cause a fire. By reducing the chance of electrical fires, circuit breakers play a critical role in keeping everyone in your household safe.

Practice

38. A standard 120-V AC household circuit consists of parallel connections of a number of electrical outlets, which are all in series with the circuit breaker for that circuit. Suppose the following devices are all plugged in and switched on at the same time.

The circuit breaker has negligible resistance and can be treated as a special type of switch.

a. Apply Ohm's law to each device and determine the current flowing through each one.

b. Use your answer to question 38.a. to determine the total current required by the operation of all three devices.

c. Determine the total resistance of all three devices.

d. Use your answer to question 38.c. to determine the total current required by the operation of all three devices. Did you get the same value as you did in question 38.b.?

e. Use your answer to questions 38.b. and 38.d. to determine the outcome of switching on all three devices at once.

f. Each time another device is switched on in the kitchen circuit, another source of resistance is added to the circuit, but the overall total resistance of the entire circuit is reduced. Although this statement sounds contradictory, it does make sense. Use your knowledge of circuits to explain why there is no contradiction here.

1.4 Summary

A digital multimeter is a powerful tool for collecting data from simple circuits. When used as a voltmeter, a parallel connection is used to determine the voltage across a component. When used as an ohmmeter, the meter is connected across a component to determine resistance values in ohms, where 1 Ω = 1 V/A. When determining the electric current that flows through a component, the multimeter is connected in series.

The use of series and parallel connections extends to the circuits themselves, where the different components can be arranged in either one of these configurations or in both. When components are connected in series, the individual voltage values are added to give the total voltage and the individual resistance values are added to give the total resistance. Since there is one path in series connections, the same current flows through each component.

Parallel connections between components mean that there is more than one path for the moving charges, so the individual values of electric current in each branch add up to give the total electric current. The voltage values remain the same across each component. The effect of having more than one path available is that more current is allowed to flow, so the total resistance is lowered. The following equation is useful for determining the total resistance in a parallel circuit:

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

1.4 Questions

Knowledge

1. State the essential components required in all electric circuits.
2. Write a mathematical expression relating voltage, current, and resistance.
3. In an electric circuit, how is the value of the current affected in the following circumstances?
   a. The voltage is doubled.
   b. The resistance in the external circuit is doubled.
4. a. State an advantage of connecting voltage sources in series.
   b. State an advantage of connecting voltage sources in parallel.
5. a. State an advantage of connecting electrical devices in series.
   b. State an advantage of connecting electrical devices in parallel.
6. Summarize the characteristics of series and parallel circuits in a table.

Applying Concepts

7. A resistor of 100 Ω is connected to a 9.00-V DC battery. Determine the current that flows through the resistor.
8. An electrical component with a resistance of 50.0 Ω is connected to an AC power supply with a voltage of 45.0 V. Determine the current that flows through the component.
9. a. Two 12.0-V DC batteries are connected to an external circuit. Determine the voltage if the two batteries are connected in series.
   b. Determine the voltage if the same two batteries are connected in parallel.
10. a. Two 50.0-Ω resistors are connected to an external circuit. Determine the total resistance if the two resistors are connected in series.
    b. Determine the total resistance if the same two resistors are connected in parallel.
11. An AC power adaptor supplies an effective voltage of 18.0 V(AC) to a 50.0-Ω and 80.0-Ω resistor connected in series. Voltmeters are connected to measure the voltage of each resistor and an ammeter measures the total current.
    a. Draw a schematic diagram of the circuit.
    b. i. Determine the total resistance of the circuit.
       ii. Determine the total current in the circuit.
       iii. Determine the voltage across the 50.0-Ω and the 80.0-Ω resistors.
       iv. What would happen to the circuit if the 50.0-Ω resistor burned out?
12. Two 1.50-V DC cells are connected in parallel. The external circuit consists of a 500-Ω and 1000-Ω resistor connected in parallel. Voltmeters are connected to measure the voltage of each resistor, and an ammeter measures the total current.
    a. Draw a schematic diagram of the circuit.
    b. i. Determine the total resistance of the circuit.
       ii. Determine the total voltage of the cells.
       iii. Determine the total current in the circuit.
       iv. Determine the voltage across the 500-Ω and 1000-Ω resistors.
       v. What would happen to the circuit if the 500-Ω resistor burned out?
13. Use the properties of series and parallel circuits to explain why voltmeters are always connected in parallel and ammeters are always connected in series.